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(54) [Title of the Invention] Illumination optical apparatus

(57) [Abstract]

[Object]

In a case of carrying out plural inclined illumination, when a pattern of a reticle is a line and space pattern constituting a longitudinal direction by a direction orthogonal to an incidence plane of illuminating light thereof, a contrast of an image thereof is improved.

[Constitution]

4 pieces of openings 24a through 24d of a spatial filter 24 as a secondary light source forming portion are respectively covered by polarizers 25A through 25D, and a polarizing direction of the polarizers 25A through 25D are set to a tangential direction of a circumference constituting an axis thereof by an optical axis AX.

[Claims]

[Claim 1]

An illumination optical apparatus characterized in an illumination optical apparatus for uniformly illuminating a predetermined region on an object by illuminating light from an illumination optical system, the illumination optical apparatus including inclined light forming means for forming inclined light illuminating the predetermined region from an oblique direction, and polarizing means for forming linearly polarized illuminating light in a direction orthogonal to an incidence plane of the inclined light for inclinedly illuminating the predetermined region by converting the inclined light.

[Claim 2]

An illumination optical apparatus characterized in an illumination optical apparatus including a light source for supplying illuminating light and a condensing optical system for uniformly illuminating a predetermined region of an object by the illuminating light;

wherein inclined light forming means for illuminating the predetermined region from an oblique direction by forming a secondary light source eccentric to an optical axis of the condensing optical system by the illuminating light is arranged between the light source and the condensing optical system; and

wherein polarizing means for forming linearly polarized illuminating light in a direction orthogonal to an incidence plane of inclined light for inclinedly illuminating the predetermined region by converting the inclined light is arranged between the inclined light forming means and the condensing optical system.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Application]

The present invention relates to an illumination optical apparatus preferable by being applied to an illumination system of a projection exposure apparatus used in fabricating, for example, a semiconductor device or a liquid crystal display device.

[0002]

[Prior Art]

When a semiconductor or a liquid crystal display device or the like is fabricated by using photolithography, there is used a projection exposure apparatus for transcribing a pattern of a photomask or a reticle (hereinafter, generally referred to as "reticle") onto a sensitive substrate. According to such a projection exposure apparatus, in accordance with highly integrated formation of a semiconductor device or the like, it is requested to bake a smaller pattern by a high resolution. As a method of realizing the request,

there is disclosed a phase shift reticle method utilizing an effect of interfering light from different transparent portions of a pattern region of a reticle in JP-B-62-50811. When the method is applied to a line and space image, basically, 0th-order diffracted light is not present, imaging is constituted only by ±1st-order diffracted light, and even in a projection optical system having the same numeral aperture, a line and space image smaller than that of a case of a reticle of a prior art can be baked by a high resolution.

[0003]

Further, as other approach for further promoting a resolution, there is proposed a method of baking a fine pattern by a high resolution and a comparatively deep depth of focus by devising an illumination optical system by the applicant (refer to, for example, Proceeding of Applied Physics Related Conference 30-a-NA-3, 4, March, 1992). In the following, the method is referred to as "plural inclined illumination method" and the method will be explained in reference to Fig. 8. First, Fig. 8(a) shows an equivalent light source portion 10 of a secondary light source portion or the like in an illumination optical system applied with the plural inclined illumination method, and in Fig. 8(a), 4 pieces of small light sources 11A through 11D are arranged along an axis x′ intersected with x axis and y axis forming an orthogonal coordinates system respectively by 45° and an axis symmetric with regard to the

axis x′ and y axis. An alignment of the small light sources 11A through 11D is suitable for a case in which a pattern of a reticle constituting an object of transcription is a line and space pattern having a long edge mainly in parallel with x axis or a long edge in parallel with y axis.

[0004]

Fig. 8(b) shows an outline constitution of a projection exposure apparatus constituting a light source by the equivalent light source portion 10 of Fig. 8(a), in Fig. 8(b), a chief ray 15A of illuminating light from the small light source 11A of the equivalent light source portion 10 is irradiated to a reticle 12 by way of a condenser lens system, not illustrated, obliquely to the optical axis AX. The equivalent light source portion 10 is conjugate with a pupil plane (incidence pupil plane) 10A of a projection optical system 13, and the pupil plane is provided with an aperture stop 13a. 0th-order diffracted light (which is also designated by notation 15A) and 1st-order diffracted light 16A are emitted from the reticle 12 substantially symmetrically relative to the optical axis AX, and the 0th-order diffracted light 15A and the 1st-order diffracted light 16A are incident on a wafer 14 as a sensitive substrate by way of the projection optical system 13 by substantially the same angle of incidence θ. In this case, the 0th-order diffracted light 15A and the 1st-order diffracted light pass through a vicinity of a

peripheral edge of the pupil symmetrically relative to the optical axis AX, and therefore, a resolution up to a limit of a function of the projection optical system 13 is achieved.

[0005]

Further, according to a system in which 0th-order diffracted light is orthogonally incident on the wafer 14 as in the prior art, since a wave front aberration of the 0th-order diffracted light and a wave front aberration of other diffracted light relative to a defocus amount of the wafer 14 significantly differ from each other, a depth of focus is shallowed. In contrast thereto, according to the constitution of Fig. 8(b), the 0th-order diffracted light and the 1st-order diffracted light are incident on the wafer 14 by the equal angle of incidence, and therefore, wave front aberrations of the 0th-order diffracted light and the 1st-order diffracted light are equal to each other when the wafer 14 is disposed before or after a position of a focal point of the projection optical system 13, and the depth of focus is deepened.

[0006]

[Problems that the Invention is to Solve]

According to the plural inclined illumination method, the method is effective for a line and space pattern 8 in an x axis direction or a y axis direction. In contrast thereto, as shown by Fig. 9, in a case of a line and space pattern 9 in which a long edge is in a direction of 45° relative to x

axis or y axis, when notation 10A designates a pupil of a projection optical system, according to diffracted light from the two small light sources 11B and 11D in four small light sources 11A through 11D of Fig. 8(a), only the 0th-order diffracted light 15B and 15D pass the pupil 10A of the projecting lens, ±1st-order diffracted light 16B and 16D do not pass the pupil 10A, and therefore, the pattern is not formed on the wafer 14 but the wafer 14 is simply illuminated uniformly. As a result, a contrast of the pattern on the wafer 14 is reduced.

[0007]

This will be shown by a simple numerical calculation. An intensity of ±1st-order diffracted light as compared with an intensity of 0th-order diffracted light is designated by notation a, and the respective small light sources 11A through 11D are regarded as point light sources. In this case, an image intensity distribution I(x) on x axis in a case of a line and space pattern which is long in a y axis direction is as follows as a sum of image intensity distributions by the respective small light sources.

[Equation 1]

$$I(x) = 4\{1 + a^2 + 2a \cdot \cos\ [(4\pi/\lambda)(\sin\theta)x]\}$$

[0008]

Here, as shown by Fig. 8(b), the angle of incidence θ is an angle made by 0th-order diffracted light or ±1st-order

diffracted light and the optical axis AX. In contrast thereto, in a case of a line and space pattern which is long in a direction intersecting with x axis or y axis by 45°, when a coordinate axis in a 45° direction is designated as x′ axis, an intensity distribution I (x′) is as follows.

[Equation 2]

$$I(x') = 2\{1 + a^2 + 2a \cdot \cos[(4\pi/\lambda)(\sin\theta)x]\} + 2\{1\}$$

$$= 4\{1 + (a^2/2) + a \cdot \cos[(4\pi/\lambda)(\sin\theta)x]\}$$

[0009]

When contrasts Cx and Cx′ of respective intensity distributions are calculated from (Equation 1) and (Equation 2) as follows.

[Equation 3]

$$Cx = 2a/(1 + a^2),\ Cx' = a/(1 + a^2/2)$$

[0010]

In this case, the following inequality is established.

$$Cx - Cx' = a/\{(1 + a^2)(1 + a^2/2)\} > 0$$

Therefore, the following inequality is established.

[inequality 4]

$$Cx > Cx'$$

[0011]

Therefore, a reduction in the contrast of the pattern which is long in the direction intersecting with x axis by 45° is shown. For example, when widths of a line and a space are equal, the intensity a of ±1st-order diffracted light becomes

$2/\pi$, and therefore, the contrasts become as shown by next equations.

$Cx = 0.906$, $Cx' = 0.529$

[0012]

Further, although in the above-described explanation, an explanation has been given by taking an example of a case of the plural inclined illumination method, even when, for example, a ring band illumination method or the like is used, it is desired to further improve the contrast of the image. In view of such a point, it is an object of the invention that in an illumination optical apparatus for illuminating a reticle or the like by positively utilizing illuminating light inclined to an optical axis, in a case in which a pattern of the reticle or the like is a line and space pattern constituting a longitudinal direction by a direction orthogonal to an incidence plane of the illuminating light, when the pattern of the reticle or the like is projected by a projection optical system, a contrast of an image thereof is made to be able to be improved by devising a side of the illumination optical apparatus.

[0013]

[Means for Solving the Problem]

According to a first illumination optical system according to the invention, as shown by, for example, Fig. 3, in an illumination optical system for uniformly illuminating

a predetermined region on an object (12) by illuminating light from an illumination optical system, the illumination optical system includes inclined light forming means (24) for forming inclined light (27B, 27C) for illuminating the predetermined region from an oblique direction, and polarizing means (25B, 25C) for forming illuminating light linearly polarized in a direction orthogonal to an incidence plane of the inclined light for inclinedly illuminating the predetermined region by converting the inclined light.

[0014]

Further, according to a second illumination optical system, as shown by, for example, Fig. 3, in an illumination optical apparatus including a light source (20) for supplying illuminating light and a condensing optical system (26) for uniformly illuminating a predetermined region on an object (12) by the illuminating light, an inclined light forming means (24) for illuminating the predetermined region from an oblique direction by forming a secondary light source eccentric to an optical axis of the condensing optical system by the illuminating light is arranged between the light source (20) and the condensing optical system (26), and polarizing means (25B, 25C) for forming illuminating light linearly polarized in a direction orthogonal to an incidence plane of the inclined light for inclinedly illuminating the predetermined region by converting the illuminated light is arranged between the

inclined light forming means (24) and the condensing optical system (26).

[0015]

[Operation]

An explanation will be given of a principle of a plural inclined illuminating method for illuminating an object by illuminating light from 4 pieces of small light sources as follows. First, according to the first illumination optical system of the invention, as shown by, for example, Fig. 3, the inclined light (27B, 27C) for illuminating the predetermined region of the object (12) from the oblique direction is formed, and beams of the inclined light (27B, 27C) are respectively polarized linearly in the direction orthogonal to the incidence plane (paper face) for the object (12) (an electric vector is oscillated in the direction orthogonal to the incidence plane). Further, linearly polarized light signifies a state in which a direction of oscillating the electric vector of a light wave is disposed in one plane, and the direction of oscillating the electric vector is defined as a direction of linearly polarized light. Further, when light reaches a boundary face of a medium, the incidence plane is defined as a face including a normal line of the face and an incident direction of light at the point. When the illumination optical system of Fig. 3 is simplified, the apparatus is as shown by Fig. 1.

[0016]

Fig. 1(a) shows the equivalent light source portion 10 of a secondary light source portion or the like of the illumination optical apparatus of Fig. 3, in Fig. 1(a), 4 pieces of the small light sources 11A through 11D are arranged along the axis x′ intersected with x axis and y axis forming the orthogonal coordinates system respectively by 45° and the axis symmetrical with regard to the axis x′ and y axis.

[0017]

Fig. 1(b) shows an outline constitution of a projection exposure apparatus using the illumination optical apparatus of Fig. 3, in Fig. 1(b), the equivalent light source portion 10 is equal to the equivalent light source portion of Fig. 1(a). The chief ray 15A of exposure light from the small light source 11A of the equivalent light source portion 10 is illuminated to the reticle 12 obliquely to the optical axis AX by way of a condenser lens system, not illustrated. The chief ray 15A corresponds to the inclined light (27B, 27C) of Fig. 3. The incidence plane of the chief ray 15A is in parallel with paper face of Fig. 1(b), and therefore, according to the invention, the chief ray 15A is incident on the reticle 12 by being linearly polarized in a direction orthogonal to the paper face of Fig. 1(b) (the electric vector is oscillated in the direction orthogonal to the paper face). Similarly, in Fig. 1(a), light from the respective small light sources 11B through 11D is

incident on the reticle 12 of Fig. 1(b) by being linearly polarized in a direction of an arrow mark of Fig. 1(a), that is, a direction orthogonal to an incidence plane with regard to the reticle 12.

[0018]

Further, the 0th-order diffracted light (which is also designated by notation 15A) and the 1st-order diffracted light 16A from the reticle 12 are incident on the wafer 14 by way of the projection optical system 13. First, when a pattern formed at the reticle 12 is a line and space pattern which is long in a direction in parallel with x axis or y axis of Fig. 1(a) constituting a pattern preferable for the prior art, a polarizing direction of illuminating light diffracted in the x direction or the y direction by the pattern is in a 45° direction relative to the pattern, and therefore, an imaging situation the same as that in randomly polarized light is brought about. Therefore, the contrast is similar to that of the prior art.

[0019]

In contrast thereto, when the pattern formed at the reticle 12 is the line and space pattern 9 which is long in the direction orthogonal to x' axis of Fig. 1(a), the 1st-order diffracted light of the illuminating light 15A from the small light source 11A is incident on the pupil of the projection optical system 13. Further, in Fig. 1(b), the x' axis is in

parallel with paper face. Here, as shown by Fig. 1(b), both of the 0th-order diffracted light 15A and the 1st-order diffracted light 15B of the illuminating light 15A are beams of S polarized light a polarizing direction (a direction of oscillating an electric vector) is in parallel with a surface of the wafer 14 (light in which the electric vector is oscillated in a direction orthogonal to paper face of Fig. 1(b)). Therefore, an interference effect on the wafer 14 becomes larger than that in the case of randomly polarized light, and an image having a high contrast is produced. Therefore, when diffracted in the x′ direction as explained in reference to Fig. 9, a drawback of the prior art that a portion of diffracted light is emitted to outside of the pupil is compensated for.

[0020]

Here, a difference in an intensity distribution by a polarizing direction will be simply described as follows. In Fig. 2, a behavior of an image face, that is, a vicinity of the surface of the wafer 14 is shown by using P polarized light (light in which a direction of oscillating the electric vector is disposed at inside of the incidence plane) and S polarized light (light in which the direction of oscillating the electric vector is orthogonal to the incidence plane). When angles of incidence of the 0th-order diffracted light 15A and the 1st-order diffracted light 16A are respectively designated by notations θ_0 and θ_1, an intensity distribution Is (x) on the

image face in the case of S polarized light is simply shown as follows by using an amplitude distribution Us (x).

[Equation 5]

$$Is(x) = |Us(x)|^2,$$

$$Vs(x) = a_0 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_0)\ x] + a_1 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_1)\ x]$$

[0021]

Therefore, the intensity distribution Is(x) becomes as follows.

[Equation 6]

$$Is(x) = a_0^2 + a_1^2 + 2a_0a_1 \cdot \cos[(2\pi/\lambda)(\sin\theta_0 - \sin\theta_1)\ x]$$

Here, coefficients a_0 and a_1 respectively designate intensities (amplitudes) of the 0th-order diffracted light and the 1st-order diffracted light. In a case of a line and space pattern having a pitch in the x' direction, in two of the four small light sources, only 0th-order diffracted light passes through the projection optical system 13, and therefore, a contrast Cs of S polarized light becomes as follows.

[Equation 7]

$$Cs = 2a_0a_1/(2a_0^2 + a_1^2)$$

[0022]

On the other hand, in a case of P polarized light, an x component and a z component of polarized light need to be considered. By expressing an amplitude distribution Up(x) on the image face in the case of P polarized light by a vector,

the following equation indicating the x component and the z component is provided.

[Equation 8]

$$
\begin{aligned}
Up(x) = (&a_0 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_0)x] \cdot \cos\theta_0 \\
&+ a_1 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_1)x] \cdot \cos\theta_1, \\
&+ a_0 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_0)x] \cdot \sin\theta_0 \\
&+ a_1 \cdot \exp[-i(2\pi/\lambda)(\sin\theta_1)x] \cdot \sin\theta_1)
\end{aligned}
$$

[0023]

Therefore, an intensity distribution $Ip(x)$ on the image face in the case of P polarized light becomes as follows.

[Equation 9]

$$
\begin{aligned}
Ip(x) &= |Up(x)|^2 \\
&= a_0^2 + a_1^2 + 2a_0a_1 \times (\cos\theta_0\cos\theta_1 + \sin\theta_0\sin\theta_1) \\
&\times \cos[(2\pi/\lambda)(\sin\theta_0 - \sin\theta_1)x]
\end{aligned}
$$

[0024]

Therefore, a contrast Cp in the case of P polarized light becomes as follows.

[Equation 10]

$$Cp = 2\, a_0a_1\cos(\theta_0 - \theta_1)/(2a_0^2 + a_1^2)$$

It is known that by comparing (Equation 7) and (Equation 10), in the case of P polarized light, the contrast becomes the contrast of S polarized light multiplied by $\cos(\theta_0 - \theta_1)$. For example, consider a case of $\sin\theta_0 = 0.4$, $\sin\theta_1 = -0.4$, $\cos(\theta_0 - \theta_1) = 0.68$, and a significant difference is produced between the case of P polarized light and the case of S polarized light.

Randomly polarized light is considered to be an average of P polarized light and S polarized light, and therefore, the contrast is (1/2)(1 + 0.68) = 0.84.

[0025]

In this way, by constituting S polarized light, the significant difference is produced in the contrast. That is, it is known that when illuminating light in a polarized state as shown by Fig. 1(a) is used, an increase in the contrast relative to that of the prior art by about 20 % is anticipated for the line and space pattern the edge of which is in parallel with the direction of being intersected with x axis and y axis by 45°, which is effective for the fine pattern.

[0026]

Further, although an explanation has been given by taking the example of the plural inclined illumination method, when the invention is applied to, for example, an annular illumination method, as shown by, for example, Fig. 7(a), light from a light source in a shape of an annular of the equivalent light source portion 10 may be converted into light linearly polarized respectively in a direction orthogonal to the incidence plane, that is, a tangential direction of a circle centering on the optical axis.

[0027]

Next, according to the second illumination optical system, as shown by, for example, Fig. 3, in order to form

inclined light, a secondary light source made to be eccentric by illuminating light from the light source is formed. When the secondary light source is irradiated as the equivalent light source 10 of Fig. 1(a), the above-described explanation is also applied to the invention as it is.

[0028]

[Embodiment]

An explanation will be given of a first embodiment of a projection exposure apparatus including the illumination optical apparatus according to the invention in reference to Fig. 3 and Fig. 4 as follows. The example applies the invention to an illumination optical system of the projection exposure apparatus. Fig. 3 shows the illumination optical system of the projection exposure apparatus of the embodiment, in Fig. 3, illuminating light from the light source 20 comprising a mercury lamp is condensed by an elliptical mirror 21, and the condensed illuminating light is incident on a fly's eye lens 23 (optical integrator) by way of a collimator lens 22. A focal plane on an emission side (reticle side) of the fly's eye lens 23 is formed with a secondary light source in a plane-like shape.

[0029]

The spatial filter 24 formed with 4 pieces of openings eccentric to the optical axis AX is provided at a vicinity of an emission end of the fly's eye lens 23. Further, polarizers

25A through 25D are respectively attached to reticle sides (or may be on sides of the light source 20) of 4 pieces of the openings of the spatial filter 24. However, in Fig. 3, only the polarizers 25B and 25C appear. Fig. 4(a) is a front view viewing the spatial filter 24 of Fig. 3 from the reticle side, Fig. 4(b) is a sectional view taken along a line AA of Fig. 4(a), as shown by Figs.4(a) and (b), the spatial filter 24 is formed with 4 pieces of openings 24a through 24d at intervals of 90° centering on the optical axis AX, and the openings are respectively covered by the polarizers 25A through 25D. Further, polarizing directions of the polarizers 25A through 25D are respectively set to a tangential direction of a circumference centering on the optical axis AX as shown by arrow marks. Therefore, beams of illuminating light emitted from the openings 24a through 24d of the spatial filter 24 are respectively polarized linearly in directions substantially in parallel with a tangential line direction of a circumference centering on the optical axis AX.

[0030]

Referring back to Fig. 3, 4 pieces of secondary light sources eccentric to the optical axis AX are formed by the spatial filter 24. Beams of illuminating light emitted from 4 pieces of the secondary light sources are incident on the reticle 12 by way of the condenser lens system 26 after passing through the respective polarizers 25A through 25D. Further,

the spatial filter 24 (polarizers 25A through 25D) is provided at a position of a front side focal point (light source side focal point) of the condenser lens system 26, and a pattern forming face of the reticle 12 is brought into a relationship of Fourier transformation with a face of arranging the spatial filter 24 with regard to the condenser lens system 26. In this case, for example, the chief rays 27B and 27C emitted from the openings 24b and 24c of the spatial filter 24 are respectively incident on the reticle 12 obliquely to the optical axis AX by way of the condenser lens system 26. Further, the chief rays 27B and 27C are respectively polarized linearly in a direction orthogonal to the incidence plane (paper face direction) with regard to the reticle 12.

[0031]

When such an illumination optical system is used, as explained in the explanation of the principle of the invention, in a case in which there is formed, for example, on the reticle 12, a line and space pattern having an edge which is long in a direction in parallel with or orthogonal to a linear line connecting the openings 24a and 24c of Fig. 4(a), the pattern can be projected onto the wafer 14 by passing the projection optical system 13 under a contrast more excellent than that of the prior art. Here, according to the apparatus of Fig. 3, the incidence side face of the fly's eye lens 23 and an object plane (reticle 12 or wafer 14) are constituted to be conjugate

with each other, and the emission side face (secondary light source 10) of the fly's eye lens 23 and a pupil plane 10A of the projection optical system 13 are constituted to be conjugate with each other. Further, other than the constitution of Fig. 3, other large polarizer may be arranged between the fly's eye lens 23 and the spatial filter 24, a portion or all of 4 pieces of the openings 24a through 24d of the spatial filter 24 may be arranged with a half-wave plate(s), and rotating angles of the respective half-wave plates may be adjusted. Also thereby, illuminating light polarized in a tangential direction of a circumference centering on the optical axis AX as shown by Fig. 4(a) is provided. In this case, depending on the polarizing direction of the other large polarizer, it is not necessary to provide the half-wave plates at all of the openings of the spatial filters 24.

[0032]

Further, by using, for example, a laser light source for emitting a linearly polarizer laser beam as a light source, when a total of the spatial filter 24 of Fig. 3 constituting the equivalent light source is illuminated by linearly polarized illuminating light, a portion or a total of 4 pieces of the openings 24a through 24d of the spatial filter 24 may be provided with a half-wave plate(s) in a pertinent rotational direction. In this case, although the half-wave plates may be provided at portions of the openings, by providing the

half-wave plates for a total of the openings, an effect is achieved in reducing a variation in illumination. When the polarizing direction is adjusted by using the half-wave plates in this way, there is not loss of illuminating light, and therefore, an illumination efficiency is excellent.

[0033]

Further, when the spatial filter 24 of Fig. 3 constituting the equivalent light source is illuminated by using an apparatus of generating circularly polarized illuminating light as a whole, the respective openings of the spatial filter 24 may be provided with quarter-wave plates in pertinent rotational directions.

[0034]

Next, a second embodiment of the invention will be explained in reference to Fig. 5. Fig. 5 shows a projection exposure apparatus of the example, and in Fig. 5, illuminating light from the light source 20 becomes substantially a parallel light beam by way of the elliptical mirror 21, a folding mirror 28 and an input lens 29. A shutter 30 is arranged between the elliptical mirror 21 and the folding mirror 28, and by closing the shutter 30 by a drive motor 31, supply of illuminating light to the input lens 29 is stopped at any time. As the light source 1, other than a mercury lens, an excimer laser light source for generating, for example, KrF laser light or the like can be used. When the excimer laser light source is used, in place

of an optical system of the elliptical mirror 21strough the input lens 29, a beam expander or the like is used.

[0035]

Further, successively from the input lens 29, a first polyhedron prism 32 having a recessed portion of a quadrangular prism shape (pyramid shape) and a second polyhedron prism 33 having a projected portion of a quadrangular prism shape (pyramid shape) are arranged. Illuminating light emitted from the second polyhedron prism 33 is split into 4 pieces of light beams at equal angles at a surrounding of the optical axis.

[0036]

The light beams split into 4 pieces are respectively made to be incident on a second group of fly's eye lenses 34A, 34B, 34C and 34D. Although in Fig. 5, only the fly's eye lenses 34A and 34B are shown, 2 pieces of the fly's eye lenses 34C and 34D are arranged in directions orthogonal to paper face of Fig. 5 by interposing the optical axis. Further, the light beam emitted from the fly's eye lens 34A is converted into a substantially parallel light beam by way of a guide optical system comprising lens systems 35A and 36A to be incident on a fly's eye lens 37A of a first group. Similarly, the light beam emitted from the fly's eye lens 34B of the second group is converted into a substantially parallel light beam by way of a guide optical system comprising lens systems 35B and 36B to be incident on a fly's eye lens 37B of the first group, and

the light beams emitted from the fly's eye lenses 34C and 34D of the second group are respectively incident on fly's eye lenses 37C and 37D of the first group by way of guide optical systems although illustration thereof is omitted.

[0037]

The first group of the fly's eye lenses 37A through 37D are arranged at intervals of 90° around the optical axis. Reticle side focal planes of the first group of the fly's eye lenses 37A through 37D are respectively formed with secondary light sources in a plane-like shape, and variable aperture stops 38A through 38D are respectively arranged at faces of forming the secondary light sources. Further, polarizers 39A through 39D are respectively arranged on reticle sides of the variable openings diaphragms 38A through 38D. Further, only the variable aperture stops 13A, 13B and the polarizers 39A, 39B appear in Fig. 5.

[0038]

Beams of illuminating light emitted by transmitting through the polarizers 39A through 39D from the variable aperture stops 38A through 38D are respectively condensed pertinently by way of an auxiliary condenser lens 40, a mirror 41 and a main condenser lens 42 to illuminate the reticle 12 substantially by a uniform illuminance. The pattern of the reticle 12 is transcribed onto a wafer 14 on a wafer stage WS by the projection optical system 13 by a predetermined

reduction magnification β. Polarizing directions of the polarizers 39A through 39D are in parallel with a tangential direction of a circumference centering on the optical axis AX. For example, a chief ray 43A of the light beam emitted by transmitting through the polarizer 39A from the variable aperture stops 38A is incident on the reticle 12 obliquely to the optical axis AX in a state of being linearly polarized to a direction orthogonal to paper face. Further, the polarizers 39A through 39D shown in Fig. 5 are substantially provided at a position of a front side focal point (light source side focal point) of a condenser lens system of a system synthesized with the auxiliary condenser lens 40 and the main condenser lens, and the position is substantially conjugate with the pupil plane 10A of the projection optical system 13.

[0039]

Also by the example, a contrast of a projected image on the wafer 14 of a line and space pattern in a predetermined direction on the reticle 12 can be improved. Further, since the second group of the fly's eye lenses 34A through 34D are provided other than the first group of the fly's eye lenses 37A through 37D, uniformity of the illuminance on the reticle 12 is further improved. Further, in Fig. 5, the polarizers 39A and 39B may be arranged at positions 44A and 44B respectively between, for example, relay optical systems, further, may be arranged at other positions. Further, when

the illuminating light from the light source 20 has already been constituted by linearly polarized light, in place of polarizers 39A and 39B, half-wave plates may be used.

[0040]

Next, a third embodiment of the invention will be explained in reference to Fig. 6 and Fig. 7. The embodiment shows an example of providing a space filter 240 having an opening 240a in a shape of an annular as shown by Fig. 6(a) on the emission side of the fly's eye lens 23 in place of the spatial filter 24 of the first embodiment shown in Fig. 3 explained above. By arranging the spatial filter 240, the emission side of the fly's eye lens 23 is formed with a secondary light source 45 in an annular shape eccentric from the optical axis AX as shown by Fig. 6(a), and light from the secondary light source 45 in the ring band shape reaches the pupil plane 10A (incident pupil plane) of the projection optical system 13 by way of the condenser lens 26, the reticle 12 as shown by Fig. 3. Here, when behaviors of the 0th-order diffracted light and the 1st-order diffracted light by a diffracting operation of the line and space pattern of the reticle 12 are considered to make the explanation simple, as shown by Fig. 6(b), the pupil plane 10A of the projection optical system 13 is formed with 0th-order diffracted light 45A in an annular shape similar to the ring band light source 45 and 1st-order diffracted light 45B in an annular shape constituted by

transversely shifting the 0th-order diffracted light 45A in the ring band shape.

[0041]

In this case, according to the example, as shown by Fig. 7(a), a polarizer 250 in an annular shape for polarizing illuminating light emitted from the secondary light source 45 in the annular shape of the equivalent light source portion 10 in a tangential direction of a circumference centering on the optical axis AX is respectively provided on the spatial filter 240. Thereby, an image having a high contrast can be provided for a fine pattern. Further, as shown by Fig. 7(b), by using the spatial filter 240 having openings for dividing the light source in the ring-like shape into respective zones in a circular arc shape, polarizers 250A through 250H may be provided on the respective zones to constitute linearly polarized illuminating light in a tangential direction of a circumference constituting an axis thereof by the optical axis AX for the respective zones.

[0042]

Further, the invention is not limited to the above-described embodiments but can naturally adopt various constitutions within the range not deviated from the gist of the invention.

[0043]

[Advantage of the invention]

According to the first and the second illumination optical apparatus of the invention, the illuminating light inclinedly incident on the object is polarized in the direction orthogonal to the incidence plane, and therefore, in a case in which the pattern on the object is a line and space pattern constituting the longitudinal direction by the direction orthogonal to the incidence plane of the illuminating light, when the pattern of the object is projected by the projection optical system, an advantage of capable of considerably improving the contrast of the image is achieved.

[Brief Description of the Drawings]

[Fig. 1]

(a) is a view showing an equivalent light source provided for an explanation of a principle of an illumination optical apparatus according to the invention, (b) is an outline constitution view showing a projection exposure apparatus using the equivalent light source of Fig. 1(a).

[Fig. 2]

Fig. 2 is a view provided for the explanation of the principle of the invention.

[Fig. 3]

Fig. 3 is a constitution view showing an illumination optical system of a projection exposure apparatus according to a first embodiment of the invention.

[Fig. 4]

(a) is a front view showing a spatial filter 24 and polarizers 25A through 25D of Fig. 3, (b) is a sectional view taken along a line AA of Fig. 4(a).

[Fig. 5]

Fig. 5 is a constitution view showing a projection exposure apparatus according to a second embodiment of the invention.

[Fig. 6]

(a) is a view showing an equivalent light source and a spatial filter 240 according a third embodiment of the invention, (b) is a view showing a behavior of diffracted light at a pupil of a projection optical system 13 by using the spatial filter 240.

[Fig. 7]

(a) is a view showing a polarized state of illuminating light from an equivalent light source of the third embodiment, (b) is a view showing an equivalent light source of a modified example of the third embodiment.

[Fig. 8]

(a) is a view showing an equivalent light source of plural inclined illumination, (b) is a view showing a behavior of diffracted light and the pupil of the projection optical system 13 when the equivalent light source of Fig. 8(a) is used.

[Fig. 9]

Fig. 9 is a view showing a case of illuminating a specific

pattern by plural inclined illumination.

[Description of Reference Numerals and Signs]

10 equivalent light source

11A through 11D small light sources

12 reticle

13 projection optical system

14 wafer

20 light source

22 collimator lens

23 fly's eye lens

24 spatial filter

24a through 24d openings

25A through 25D polarizers

26 condenser lens system